

Magnetic resonance imaging evaluation of olfactory bulb angle and soft palate dimensions in brachycephalic and nonbrachycephalic dogs

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OBJECTIVE

To determine from MRI measurements whether soft palate length (SPL) and thickness are correlated in dogs, evaluate the association between the olfactory bulb angle (OBA) and degree of brachycephalia, and determine the correlation between soft palate–epiglottis overlap and OBA in dogs.

ANIMALS

50 brachycephalic and 50 nonbrachycephalic client-owned dogs without abnormalities of the head.

PROCEDURES

Medical records and archived midsagittal T2-weighted MRI images of brachycephalic and nonbrachycephalic dogs' heads were reviewed. Group assignment was based on breed. Data collected included weight, SPL and thickness, OBA, and the distance between the caudal extremity of the soft palate and the basihyoid. Soft palate length and thickness were adjusted on the basis of body weight.

RESULTS

Brachycephalic dogs had significantly thicker soft palates and lower OBAs, compared with findings for nonbrachycephalic dogs. There was a significant negative correlation ($r^2 = 0.45$) between OBA and soft palate thickness. The correlation between SPL and OBA was less profound ($r^2 = 0.09$). The distance between the caudal extremity of the soft palate and the basihyoid was shorter in brachycephalic dogs than in nonbrachycephalic dogs. The percentage of epiglottis–soft palate overlap significantly decreased with increasing OBA ($r^2 = 0.31$).

CONCLUSIONS AND CLINICAL RELEVANCE

Results indicated that MRI images can be consistently used to assess anatomic landmarks for measurement of SPL and thickness, OBA, and soft palate-to-epiglottis distance in brachycephalic and nonbrachycephalic dogs. The percentage of epiglottis–soft palate overlap was significantly greater in brachycephalic dogs and was correlated to the degree of brachycephalia. (*Am J Vet Res* 2018;79:170–176)

Brachycephalia refers to cranial chondrodysplasia of the skull, which results in a shortened longitudinal axis. Dog skulls are generally classified as being dolichocephalic (long longitudinal axis), mesocephalic (midlength longitudinal axis), or brachycephalic, although this subclassification is often poorly defined¹ and has been traditionally categorized on the basis of skull radiographic findings. A brachycephalic skull has shortened facial and nasal bones,

small nasal cavity and frontal and maxillary sinuses, and wide orbits. Various skull indices have previously been used to assess head conformation in dogs,^{2,3} and these rely on accurate measurements of orthogonal skull radiographic views. Recently, Hussein et al⁴ used MRI measurements of the OBA to determine the degree of brachycephalia in dogs. There was a strong correlation between OBA and traditional head conformation index value; small OBAs were significantly associated with high head conformation index values (ie, extreme brachycephalia).

Brachycephalic obstructive airway syndrome is a common condition affecting the upper airway of brachycephalic dogs. It is a complex syndrome with many anatomic abnormalities, which can have a cumulative effect leading to clinical signs of BOAS.⁵ Common primary anatomic abnormalities include stenotic nares, an elongated and thickened soft palate, enlarged tonsils, compressed nasal mucosa due to

ABBREVIATIONS

%SPED	Soft palate-to-epiglottis distance as a percentage of SPL
BOAS	Brachycephalic obstructive airway syndrome
CI	Confidence interval
OBA	Olfactory bulb angle
SPED	Soft palate-to-epiglottis distance
SPL	Soft palate length
SPLw	Soft palate length relative to weight
SPT	Soft palate thickness
SPTw	Soft palate thickness relative to weight

excessive growth of nasopharyngeal turbinates, and a hypoplastic trachea.⁶⁻⁸ Secondary (or consequential) abnormalities, which include laryngeal collapse and eversion of laryngeal saccules, are most likely related to chronically increased negative airway pressure.⁹ Common respiratory signs of BOAS include stridor and stertor, dyspnea, tachypnea, cough, and exercise intolerance, which may progress to cyanosis and syncope episodes.¹⁰ The severity of respiratory signs is reported to be associated with the degree of airway obstruction.¹¹

Diagnosis of BOAS in dogs is traditionally made by a combination of history and findings of clinical examination, radiography, and detailed examination of the upper airways during anesthesia. Computed tomography is useful in the investigation of BOAS^{12,13} and can be used to indirectly measure the OBA by identifying the position of the ethmoidal fossae.⁴ To the authors' knowledge, there is no described and recognized technique to measure OBA from CT images. Brachycephalic obstructive airway syndrome is generally considered to be a disease that requires surgical treatment.^{5,14} Surgical correction is usually multifactorial and attempts to reduce the obstruction in the upper airway to allow easier passage of air. This is often achieved with a combination of, but not limited to, rhinoplasty, staphylectomy, laryngeal sacculectomy, tonsillectomy, lateralization of the arytenoid cartilage,^{5-7,15} and intranasal surgery including ablation of nasal choanae and correction of septal deviations.¹⁶

There are no published reports of studies evaluating both palatal structures and morphological characteristics of the skull with MRI, to the authors' knowledge. Furthermore, the length and thickness of the soft palate of dolicho- and mesocephalic dogs (ie, nonbrachycephalic dogs), as determined from MRI images, have not been compared with those of brachycephalic dogs. It is possible that MRI may be a helpful technique to aid in surgical planning for treatment of dogs with BOAS, but its usefulness for this purpose is as yet unknown.

The intent of the study reported here was to determine whether midsagittal T2-weighted skull MRI images could be used to directly assess OBA and palatal structures and, in particular, to assess the length and thickness of the soft palate in nonbrachycephalic dogs and brachycephalic dogs with signs of BOAS and to evaluate the degree of soft palate overlap in relation to the basihyoid. On the basis of the MRI measurements, the objective was to determine whether SPL and SPT are correlated, evaluate the association between the OBA and degree of brachycephalia, and determine the correlation between soft palate-epiglottis overlap and OBA in dogs. The hypotheses were that brachycephalic dogs would have longer and thicker soft palates, relative to weight, compared with findings for nonbrachycephalic dogs; there would be a correlation between MRI-derived OBA and the presence of signs of BOAS; and the SPED would be smaller in dogs with signs of BOAS.

Materials and Methods

Medical records and archived images were searched to identify dogs that underwent MRI of the head (for which the findings were normal) between 2010 and 2016. Dogs were included in the study if the archived images included a midsagittal T2-weighted image of the head and if a complete history and medical record were present. Dogs were excluded if there was any evidence of mass effect within any part of the cranium or macroscopic disease affecting the olfactory bulb or oropharyngeal structures (eg, neoplasia and congenital brain or skull abnormalities) or if the dogs had had any previous BOAS or pharyngeal or laryngeal surgery.

Medical records were reviewed, and the information collected included signalment, breed, sex, age, weight, and presence or absence of clinical signs of BOAS. Dogs with clinical signs of BOAS included those that had a chronic history of snoring, stertorous respiration at rest (which could be coupled with syncope, gagging, or regurgitation), or both; brachycephalic dogs were not excluded because of the absence of these signs. On the basis of breed, dogs were then allocated to 1 of 2 groups: dogs with brachycephalic skulls or dogs with dolicho- or mesocephalic (ie, nonbrachycephalic) skulls.

Each dog was anesthetized with agents selected by an anesthesiologist. All dogs were intubated with an endotracheal tube and positioned in sternal recumbency, with the head and neck extended into a knee coil. Each dog was mechanically ventilated. Images were acquired with a 0.4-T open-magnet MRI,^a and images (DICOM standard) were viewed with commercially available software.^b Images were examined by a single image reviewer (DAB), who was unaware of the dog's breed and clinical history. Midsagittal images were identified as those with both the largest view of the cerebellum (including the midvelum ridge) and the interthalamic adhesion. Soft palate length was measured from the most caudal aspect of the palatine bone to the most caudal point of the soft palate. Soft palate thickness was measured from the widest point ventrodorsally at a level perpendicular to the line of SPL measurement (**Figure 1**). The OBA was calculated in accordance with the description by Hussein et al.⁴ Briefly, the OBA was the angle between the medial rhinal sulcus and a line between the hard palate and the intercondylar notch of the foramen magnum. The SPED was measured between the extremity of the soft palate and a line perpendicular to the axis of SPL that intersected the basihyoid. The perpendicular line from the basihyoid was chosen in preference to the cranial extremity of the epiglottis because this structure was consistently and easily identified on MRI images. Once the SPED was determined, values were designated as positive if there was no overlap or negative if the extremity of the soft palate extended to the base of the epiglottis. To adjust for differences

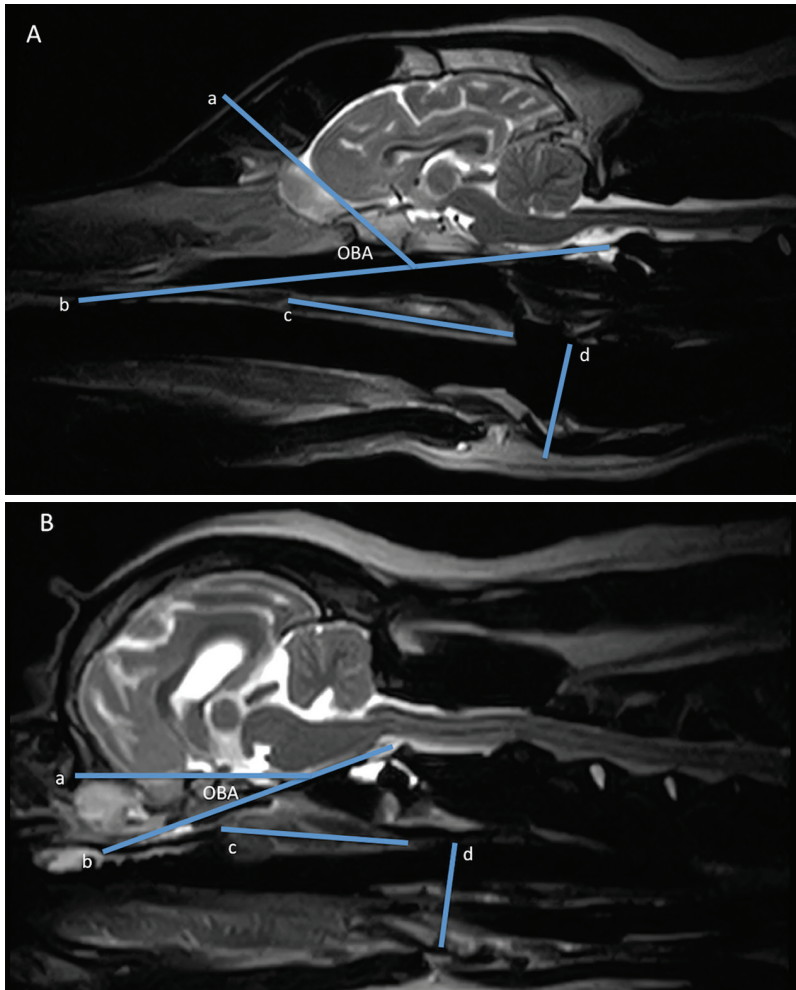


Figure 1—Representative midsagittal T2-weighted MRI reconstructions of the heads of 2 dogs (a Labrador Retriever [A] and a Pug [B]) to illustrate measurement of the OBA and SPED in mesocephalic (ie, nonbrachycephalic) and brachycephalic breeds. The OBA is the angle between the medial rhinal sulcus (line a) and a line between the hard palate and the intercondylar notch of the foramen magnum (line b). Line c indicates SPL. A line perpendicular to line c is drawn, intersecting the basihyoid (line d). The SPED is measured between the extremity of the soft palate and a line perpendicular to the long axis of the soft palate that intersects the basihyoid (line d). The perpendicular line from the basihyoid was chosen in preference to the cranial extremity of the epiglottis because this structure was consistently and easily identified on MRI images.

in the physical size, SPL and SPT values for each dog were standardized relative to the dog's weight (ie, SPLw and SPTw). For each dog, the percentage of SPED relative to the SPL (ie, %SPED) was calculated by dividing SPED by unadjusted SPL and multiplying by 100. The same reviewer obtained measurements of all variables of interest for all dogs twice on different days, and the mean values for those 2 measurements were calculated and used as the final values for a given dog. If there was > 10% difference between any of the 2 measurements, a third measurement was obtained and the mean of all 3 values was calculated for use as the final value for that dog. From the individual %SPED values, an overall mean was calculated for each study group.

Statistical analysis

Normal Gaussian distributions of data were determined with a Shapiro-Wilk test. Continuous variables (weight, SPL, SPT, OBA, SPLw, SPTw, SPED, and %SPED) were summarized as mean and 95% CI. Data that were normally distributed were compared with a 2-tailed *t* test, and data that were not normally distributed were compared with a Mann-Whitney *U* test. Linear regression analysis was performed with determination of a Pearson correlation coefficient for comparisons between values. Comparison between groups was done by a univariate ANOVA and with a Tukey-Kramer method analysis. For all analyses, values were considered significant at a value of $P \leq 0.05$. Data were stored and analyzed with commercially available software.^c

Results

Data from 100 dogs were included for analysis. Of the 100 dogs, 50 were dolicho- and mesocephalic (ie, nonbrachycephalic) with no clinical signs of BOAS and 50 were brachycephalic with clinical signs of BOAS. Breeds in the nonbrachycephalic group included Labrador Retriever ($n = 10$), Cocker Spaniel (5), Border Collie (5), Golden Retriever (4), Jack Russell Terrier (4), Greyhound (3), Border Terrier (3), Springer Spaniel (2), German Shepherd Dog (2), Toy Poodle (2), and Great Dane, Cairn Terrier, Saint Bernard, Coton De Tulear, Dachshund, Corgi, Akita, Doberman Pinscher, Hungarian Vizsla, and Beagle (1 each). Of the nonbrachycephalic dogs, 24 were male (8 neutered) and 26 were female (7 neutered). Nonbrachycephalic dogs had a mean weight of 21.8 kg (95% CI, 18.4 to 25.2 kg); median weight was 19.3 kg. Nonbrachycephalic dogs had a mean and median age of 78 and 87 months, respectively. Breeds in the brachycephalic group included French Bulldog ($n = 14$), British Bulldog (10), Pug (9), Cavalier King Charles Spaniel (5), Chihuahua (3), Staffordshire Bull Terrier (3), Boxer (2), Japanese Chin (2), and Lhasa Apso and Shar Pei (1 each). Brachycephalic dogs had a mean weight of 15.2 kg (95% CI, 12.7 to 17.7 kg); median weight was 12.2 kg. Brachycephalic dogs had a mean and median age of 58 and 50 months, respectively. There was a significant difference in weight between groups, with nonbrachycephalic dogs being heavier. In both groups, all dogs were skeletally mature and > 1 year old (or > 2 years old for giant-breed dogs), and nonbrachycephalic dogs were significantly older.

For the nonbrachycephalic group, mean SPL was 65.7 mm (95% CI, 62.1 to 69.3 mm) and mean SPT was 7.57 mm (95% CI, 6.59 to 8.55 mm). When corrected for weight, mean SPLw was 3.85 mm/kg (95% CI, 3.31 to 4.39 mm/kg) and mean SPTw was 0.42 mm/kg (95% CI, 0.36 to 0.49 mm/kg; **Figure 2**). For the

brachycephalic group, mean SPL was 50.9 mm (95% CI, 47.9 to 53.9 mm) and mean SPT was 10.4 mm (95% CI, 9.2 to 11.7 mm). When corrected for weight, mean SPLw was 4.52 mm/kg (95% CI, 3.71 to 5.33 mm/kg) and mean SPTw was 0.82 mm/kg (95% CI, 0.73 to 0.91 mm/kg). Compared with the nonbrachycephalic dogs, brachycephalic dogs had significantly ($P < 0.001$) greater SPTw but there was no significant ($P = 0.22$) difference in SPLw.

The mean OBA for the nonbrachycephalic group was 48.7° (95% CI, 47.0° to 50.4°). The mean OBA for the brachycephalic group was 30.1° (95% CI, 27.2° to 33.0°). The difference in OBA between groups was significant ($P < 0.001$). Results of linear regression analysis indicated that OBA significantly decreased with increasing SPLw ($P = 0.003$) or SPTw ($P < 0.001$), with strong negative correlation between SPTw and OBA ($r^2 = 0.45$; **Figure 3**). There was a weak negative correlation between SPLw and OBA ($r^2 = 0.09$).

The mean SPED for the nonbrachycephalic group was 13.1 mm (95% CI, 11.7 to 14.5 mm). The mean SPED for the brachycephalic group was 2.1 mm (95% CI, 0.7 to 3.5 mm). All nonbrachycephalic dogs had a discernable gap between the distal soft palate and the level of the base of the epiglottis and therefore had a positive value for SPED. In the brachycephalic dogs, some dogs had a gap (32/50), whereas some had overlap (18/50). Those brachycephalic dogs that had overlap had a negative value for SPED with a mean overlap SPED of 3.34 mm (95% CI, 2.32 to 4.32 mm). Of the brachycephalic dogs without overlap, the mean SPED was 5.21 mm (95% CI, 4.16 to 6.26 mm). The difference in SPED between groups was significant ($P < 0.001$). As a percentage of unadjusted SPL, the mean %SPED was 20.22% (95% CI, 18.35% to 22.09%) for the nonbrachycephalic group and 4.69% (95% CI, 1.87% to 7.56%) for the brachycephalic group. The difference in %SPED between groups was significant ($P < 0.001$). Results of linear regression analysis indicated that %SPED significantly ($P < 0.001$) increased with increasing OBA ($r^2 = 0.31$).

None of the SPL measurements were repeated for a third time. The SPT measurement was repeated in 1 dog each for the brachycephalic and nonbrachycephalic groups. Measurement of the OBA was repeated in 1 dog in the nonbrachycephalic group and in 7 dogs in the brachycephalic group. The SPED measurement was repeated for 6 dogs in the nonbrachycephalic group and in 7 dogs in the brachycephalic group.

Discussion

The results of the present study were similar to findings of previous studies,^{4,17} which indicated that the difference in SPT is greater than the difference in SPL between brachycephalic and nonbrachycephalic dogs. To the authors' knowledge, this is the first study to have identified a significant quantifiable difference in SPTw, as determined from MRI images, between brachycephalic and nonbrachycephalic dogs and to

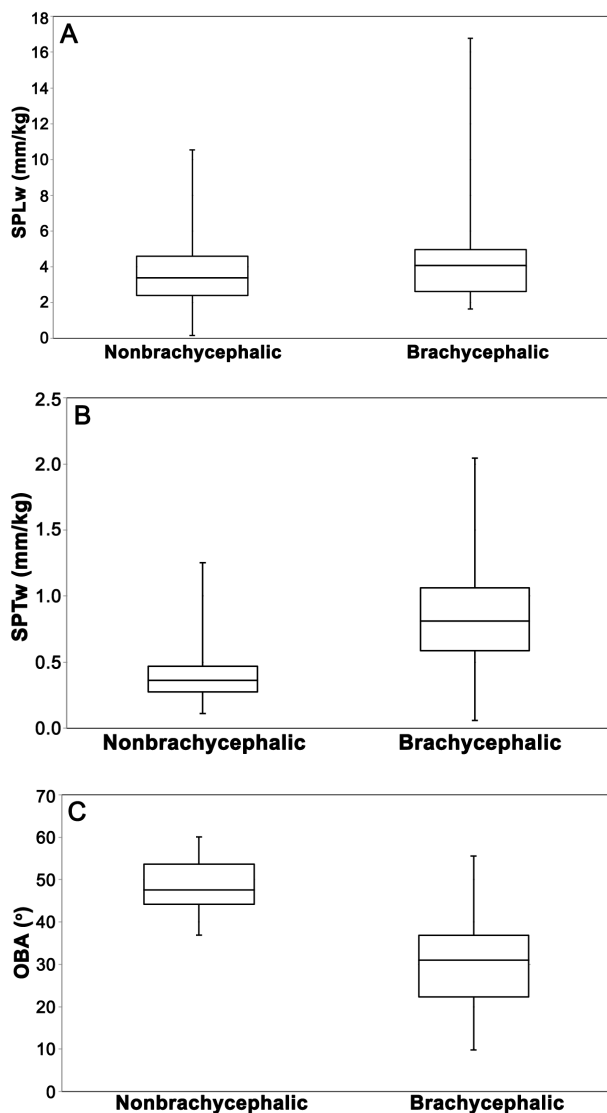


Figure 2—Box-and-whisker plots of SPLw (A), SPTw (B), and OBA (C) determined from T2-weighted MRI reconstructions of the heads of 50 dolicho- and mesocephalic (ie, nonbrachycephalic) and 50 brachycephalic dogs. The dogs' heads had no detectable abnormalities on MRI images. Soft palate length was measured from the most caudal aspect of the palatine bone to the most caudal point of the soft palate. Soft palate thickness was measured from the widest point ventrodorsally at a level perpendicular to the line of SPL measurement. The SPL and SPT values for each dog were standardized relative to the dog's weight (ie, SPLw and SPTw). The OBA was the angle between the medial rhinal sulcus and a line between the hard palate and the intercondylar notch of the foramen magnum. For each box, the horizontal line represents the mean value and the upper and lower boundaries represent the 75th and 25th percentile, respectively. Whiskers represent the maximum and minimum values. Mean values of SPTw and OBA differed significantly (both $P < 0.001$) between the 2 groups.

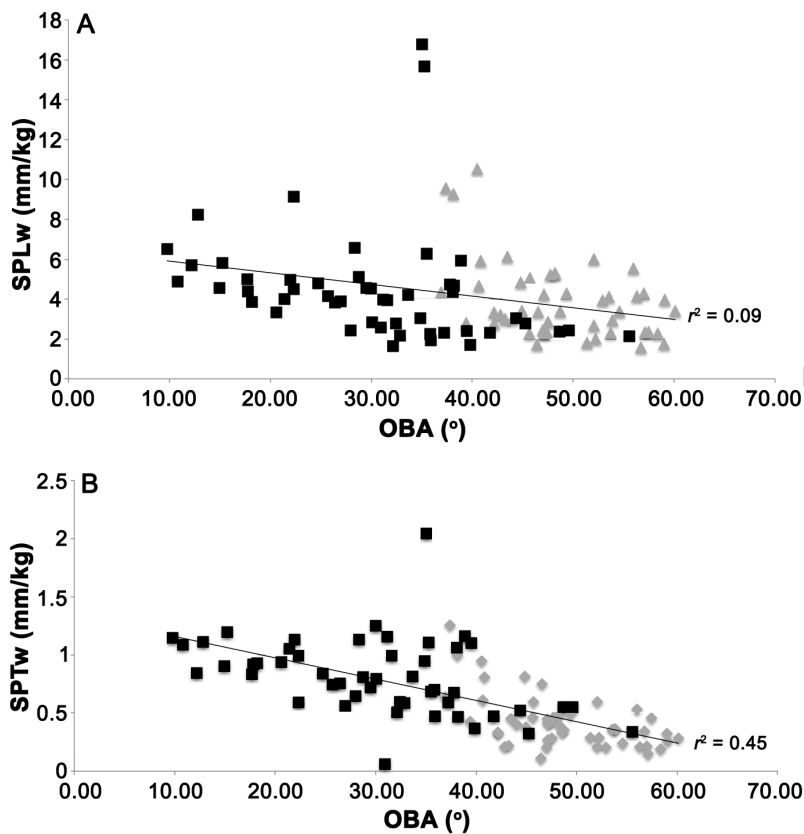


Figure 3—Scatter graphs of values of SPLw (A) and SPTw (B) versus OBA determined from T2-weighted MRI reconstructions of the heads of the 50 nonbrachycephalic (squares) and 50 brachycephalic (triangles or diamonds) dogs in Figure 2. In each panel, the linear regression line is shown. See Figures 1 and 2 for remainder of key.

have correlated signs of BOAS with OBA. Brachycephalic dogs with signs of BOAS had a significantly lower mean OBA, higher SPTw, and higher %SPED, compared with values for nonbrachycephalic dogs with no signs of BOAS. Moreover, the present study is the first to attempt to quantify the degree of overlapping of the soft palate past the base of the epiglottis, as determined from MRI images, by use of a consistent identifiable landmark.

Compared with nonbrachycephalic dogs, the degree of soft palate–epiglottis overlap was significantly higher in brachycephalic dogs (ie, dogs with lower OBAs). In the MRI images, the soft palate–epiglottis overlap measurements were obtained at the point of the basihyoid because this structure is consistently identified as a fixed point. The cranial extremity of the epiglottis can be distorted by nearby similarly attenuating structures, and it can be displaced by the endotracheal tube in anesthetized animals, whereas the hyoid apparatus is more rigidly fixed within the larynx. In addition, the cranial extremity of the epiglottis can difficult to distinguish in MRI images because of the lack of tissue differentiation from the ventral aspect of the oropharynx. The SPED, as measured in the present study, was therefore a substantial underestimate of the degree of actual overlap of the

extremities of the soft palate and the epiglottis. The length of the epiglottis was not measured in this study, and it remains undetermined whether a BOAS-affected dog with a long epiglottis would have similar clinical signs as a BOAS-affected dog with an overly long soft palate.

In the present study, %SPED was calculated because a large absolute SPED value may have been less clinically relevant in a larger dog; thus, SPED was corrected with regard to unadjusted PL. Most %SPED values were positive, indicating that the extremity of the soft palate did not extend further than the base of the basihyoid. It may be of future interest to determine whether %SPED and the length of the epiglottis are correlated and ascertain whether brachycephalic dogs also have an overly long epiglottis, which further compounds upper airway obstruction. The %SPED for the brachycephalic group was significantly greater than that for the nonbrachycephalic group in the present study. The authors believe %SPED to be of clinical importance for assessment of the extent of upper airway obstruction in dogs. In this study, the difference in %SPED between brachycephalic and nonbrachycephalic dogs was 15.5%.

It is possible that when determining the length of the soft palate for resection in a brachycephalic dog with BOAS, one could consider removal of up to 15% of the SPL to adjust the palate to an acceptable length for a dolicho- or mesocephalic dog. However, owing to the retrospective nature of the present study and that fact that it was not a clinical study, firm conclusions in this regard cannot be made. Nonetheless, it is interesting to note that in a histologic study,¹⁸ the palatinus muscle was not evident in the most aboral 16% of the soft palate. The authors therefore postulate that removal of the most aboral 15% of the soft palate may not reduce muscular tone and not affect normal physiologic function of the palatal structures. From the findings of the present study, it appears that sagittal MRI images can be used to determine whether SPL, SPT, or both are abnormal, compared with the mean values found in this data set. This information may be used to determine whether a folded palatoplasty or staphylectomy should be performed.¹⁷ It can be argued, however, that a thickened soft palate is attributable to edema caused by chronic inflammation secondary to turbulent airflow. Reduction in airway resistance by shortening the soft palate without reducing thickness may reverse these secondary inflammatory changes.

In the present study, there was significantly greater variability of SPTw and OBA among brachycephalic dogs than among nonbrachycephalic dogs. This difference highlights the importance of presurgical planning for dogs with BOAS. The lack of significant difference in SPLw between groups supported the idea that SPL may not be very important as a determining factor in the development of BOAS. However, given that development of BOAS is multifactorial and not just correlated to soft palate abnormalities, it is not possible to confirm this statement. The dogs in the nonbrachycephalic group of the present study had a higher mean weight than dogs in the brachycephalic group. Although the weight difference was not significant, it is uncertain whether a linear relationship exists between body weight and the biometric data collected during this study. It could be that unadjusted SPL and OBA are more relevant to the presence of clinical signs of BOAS than is SPLw, and further investigation is warranted.

All measurements were made by 1 image reviewer to avoid inter-reviewer variability. Intrareviewer repeatability was high for measurements of SPL, SPT, and the nonbrachycephalic group's OBA, but lower for the brachycephalic group's OBA and brachycephalic group's SPED. Measurements of SPL and SPT on MRI images are easy to perform accurately because of the presence of air in the oropharynx and nasopharynx that provides clear delineation of anatomic borders. Measurement of the OBA is slightly more subjective. The OBA measurements were more variable in brachycephalic dogs in the present study, and this led to a lower repeatability of results for OBA measurement in this group. The measurement of SPED also had lower repeatability because of the interpretation of exactly where the basihyoid was located; for some images, the basihyoid was difficult to discern from other hyoid cartilages.

The present study had various limitations. The retrospective nature of the study design reduced the statistical power. In the anesthetized dogs, the endotracheal tube may have affected the position of the soft palate and distorted the apparent lengths and thicknesses. For each dog, the largest appropriate endotracheal tube was used; it was therefore assumed that the degree of distortion that might have influenced measurements was similar in both groups. Dogs were selected sequentially after they had undergone head MRI that did not reveal pathological brain changes. Although the authors consider it unlikely, there remains a potential selection bias. Owing to the design of the study, it was not possible for the image reviewer to be blinded to the skull conformation type; therefore, there is a potential reviewer bias. No grading system was used to classify the extent of BOAS in the brachycephalic dogs, and thus no correlation could be drawn between OBA or SPTw and the severity of clinical signs. It is interesting to note that in this study, all brachycephalic dogs had at least 1 clinical

sign of BOAS. As well as the brachycephalic dogs with signs of BOAS, it would have been of interest to include a population of brachycephalic dogs without signs of BOAS for comparison of OBAs and palatal measurements between those 2 groups in an attempt to determine the clinical importance of the study results. In reality, some dogs cannot be easily dichotomized as brachycephalic or nonbrachycephalic; even with breed standards, skull shape varies among individuals. A recent study¹⁹ described a semiobjective grading index for BOAS in dogs; however, given the retrospective nature and omissions in the medical records used in the present study, it was not possible to apply this index to the study dogs. Prospective MRI studies in which an objective measure of BOAS severity is implemented are warranted to determine correlations between OBA, SPTw, or %SPED and clinical signs in affected dogs. Notwithstanding, results of the present study indicated that there is a positive correlation between the OBA and SPTw and a weak correlation between the OBA and SPLw (measured on MRI images) for brachycephalic dogs with signs of BOAS. Thus, the data suggested that OBA is associated with the degree of brachycephalia and that brachycephalic dogs with lower OBAs have thicker soft palates. Measurement of the OBA on midsagittal MRI images of the head can be considered a useful tool for predicting the presence of BOAS in dogs.

Footnotes

- a. APERTO inspire (2008) Lucent, Hitachi, Tokyo, Japan.
- b. OsiriX, version 5.0.2, 32-bit, Pixmeo, Geneva, Switzerland.
- c. Excel for Mac 2011, Microsoft, Redmond, Wash.

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